APPLICATION

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TITLE: A CMOS RADIATION-MEASURING CIRCUIT WITH A VARIABLE THRESHOLD

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A CMOS RADIATION-MEASURING CIRCUIT WITH A VARIABLE THRESHOLD

BACKGROUND

This invention relates to a CMOS radiation-measuring circuit with a variable threshold.

A complementary-symmetry MOSFET (CMOS) radiation-measuring circuit may include transistors configured to provide a digital output that changes from one state to another when the radiation dose absorbed by the circuit exceeds a threshold. The size of the devices used in the CMOS radiation-measuring circuit determines the radiation dosage that will cause the digital output of the CMOS radiation-measuring circuit to change from one digital state to another digital state. Hence, the design of a CMOS radiation-measuring circuit requires careful consideration of the size of transistors in the circuit.

When the voltage applied between the gate and source terminals of a MOSFET exceeds a certain voltage, the MOSFET turns on. This voltage is referred to as the threshold voltage. The threshold voltages of p-channel type MOSFET (pMOS) and n-channel type MOSFET (nMOS) devices are sensitive to ionizing radiation. Generally, the threshold voltage of an irradiated MOSFET device shifts due to an increase of trapped charge in the oxide and interface states.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a system that includes a radiation sensor.

FIG. 2 is a schematic of a radiation sensor with a variable

5   threshold.

DETAILED DESCRIPTION

As shown in FIG. 1, a CMOS radiation-measuring circuit 1 with a variable threshold may be exposed to a source of radiation 2 to determine when a threshold radiation dose has

10   been reached. The radiation-measuring circuit 1 includes a radiation sensor 3 and an auxiliary circuit 4. The radiation-measuring circuit 1 may be used, for example, as a built-in radiation-measuring circuit in standard circuits to prevent malfunction due to radiation hazards. The CMOS radiation-

15   measuring circuit with a variable threshold may have a wide range of applications in spacecraft design, medicine, nuclear plant and personal dosimetry. The radiation-measuring circuit may be used as or incorporated in a dosimeter. Depending on its specific application, dose ranges from millirads to tens of

20   megarads may be detected by the circuit.

FIG. 2 illustrates details of a CMOS radiation-measuring circuit that may be used to measure a variable radiation dose. A pMOS transistor P1 serves as the radiation sensor 3. This

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transistor is coupled to the auxiliary circuit 4 that includes a

current mirror with pMOS transistors P2 and P3.   The pMOS

current mirror generates a current that is a multiple of the

reference current source (I_{sens}).   For example, in one

5   implementation, the current through the second side of the

current mirror (transistor P3) is ten times the reference

current (I_{sens}) through the first side of the current mirror

(transistor P2).   The source terminal of the radiation-sensing

transistor P1 is coupled to a first side of the current mirror

10   (transistor P2) through a resistive element N1.   Thus, the

radiation-sensing transistor P1 is biased through the resistive

element N1 and the transistor P2.

The resistive element N1 causes the voltage at the drain

terminal of the transistor P2 to differ from the voltage (V_a) at

15   the source terminal of the radiation-sensing transistor P1.   The

resistance of the element N1 should not be affected by

radiation.   In some implementations, the resistive element N1

may include a resistor.   However, the use of a transistor as the

resistive element N1 can provide better efficiency and better

20   control because it uses less silicon area.   In one embodiment,

the resistive element N1 includes an nMOS transistor with its

gate terminal shorted to its drain terminal. The transistor P2

that forms the first side of the current mirror may have its

gate terminal shorted to its drain terminal.   The source

terminal of the sensing transistor P1 also is coupled to an
output load nMOS transistor N2 that is coupled to the second
side of the current mirror (transistor P3).

The width (W) and length (L) of a channel region of a pMOS
5   transistor affects its behavior. The current through the left-
hand side of the circuit (I_{sens}) may be approximated by:

$$I_{sens} = \mu p C_{ox}(W/L)(V_a-|V_{tP1}|)^2$$

where μp is the hole mobility, C_{ox} is the gate oxide capacitance,
and V_{tP1} is the threshold voltage of transistor P1. The
10   dimensions of the devices used in the radiation-measuring
circuit can be selected so that when the circuit is not exposed
to radiation and the input voltage (V_{in}) across the body terminal
and the source terminal of the radiation-sensing transistor P1
is zero, the gate-source voltage of the radiation-sensing
15   transistor P1 is slightly beyond its non-irradiated threshold
voltage value. Therefore, even when the radiation-measuring
circuit is not exposed to radiation, the radiation-sensing
transistor P1 is enabled.

Additionally, when the circuit is not exposed to radiation,
20   the current I_{sens} is magnified by the current mirror (transistors
P2 and P3). The circuit is designed so that the voltage (V_a) is
above the threshold voltage of transistor P1 (V_{tP1}). That
voltage, which appears at the gate terminal of the output load
transistor N2, is not large enough to sufficiently turn on the

output load transistor.   In summary, when the CMOS radiation-
measuring circuit is not exposed to radiation, the second side
of the current mirror (transistor P3) is on, the output load
transistor N2 is almost turned off, and the current that flows
through the second side of the current mirror is much larger
than I_{sens}.   The value of the output voltage (V_{out}) is pulled to
the supply voltage V_{dd} through the transistor P3.   In that mode
of operation, the output voltage (V_{out}) represents a high digital
state.

However, when the circuit is irradiated, the absolute value
of the threshold voltage for the radiation-sensing transistor P1
increases, as described above.   Once the threshold voltage
increases above the value of the voltage (V_a), the radiation-
sensing transistor P1 turns off.   As can be seen from the
approximation for I_{sens} in the above equation, when P1 is turned
off, the current (I_{sens}) through the first side of the current
mirror (transistor P2) will drop to zero.   As a result, the
current that flows into the output load transistor N2 also
decreases.   At this point, the voltage (V_a) is only slightly less
than the supply voltage V_{dd} as a result of the voltage drop
across the resistive element N1 and the transistor P2.   This
voltage (V_a), which also appears at the gate terminal of the
output load transistor N2, causes the output load transistor N2
to turn on.   The output voltage (V_{out}) of the CMOS radiation-

measuring circuit is, thus, coupled to ground through the output

load transistor N2. In that mode of operation, the output

voltage (V_{out}) represents a digital low state. Therefore, the

radiation-measuring circuit provides a digital output.

5   To allow the radiation-measuring circuit to sense different

radiation doses, the threshold voltage of the radiation-sensing

transistor P1 can be modified by changing the body bias of the

transistor through the input voltage (V_{in}). The body bias is the

voltage between the body terminal and the source terminal of the

10   transistor V_{bs}. The voltage used to adjust the body bias may be

applied, for example, from an external source that allows a user

to adjust the value of V_{in} when the CMOS radiation-measuring

circuit is exposed to radiation. Alternatively, the voltage

used to adjust the body bias may be an integrated voltage source

15   based on bandgap or charge pump circuits that a user may adjust

using software.

As discussed earlier, changing the threshold voltage of the

radiation-sensing transistor P1 changes the dose required to

turn off that transistor. Therefore, the dose required to

20   change the output of the CMOS radiation-measuring circuit from

one digital state to another can be altered by changing the body

bias of the radiation-sensing transistor P1. A single

radiation-measuring circuit can, therefore, be used to measure

different dose values that the circuit may be exposed to.

The auxiliary circuit to which the radiation-sensing transistor P1 is coupled preferably is composed of components that, as a whole, are insensitive to threshold voltage shift due to radiation exposure. Preferably, pMOS transistors are used in the current mirror because this configuration tends to be less sensitive to threshold voltage shifts provided the threshold voltages of each pMOS transistor shift by the same amount. Resistive element N1 and the output load transistor N2 preferably are nMOS transistors because the absolute value of the threshold voltage shift in an nMOS transistor remains substantially unchanged. More specifically, the charge trapped in the oxide is positive for both nMOS and pMOS devices, whereas the interface state charge is positive for a pMOS and negative for an nMOS. Because these charge components have the same sign in a pMOS device, the threshold voltage of the pMOS device is shifted toward a more negative value. In contrast, because these charge components have opposite signs in an nMOS device, they induce a competing effect in threshold voltage shift and the resulting sign of the threshold voltage shift in an nMOS device depends on which charge component's contribution is dominant. Therefore, the absolute value of the threshold voltage shift is usually much higher in pMOS transistors than nMOS transistors.

An advantage of the foregoing techniques is the radiation dose that may be measured by the radiation-measuring circuit 1 need not be fixed. Therefore, CMOS radiation-measuring circuits need not incorporate several radiation-measuring circuits to

5   measure different radiation doses. Also, the auxiliary circuit, used in the radiation-measuring circuit can be relatively impervious to radiation-induced changes.

Various modifications may be made. For example, the radiation-measuring circuit can include an nMOS current mirror,

10 an nMOS radiation-sensing transistor, a pMOS resistive element coupled to the radiation-sensing transistor and a pMOS output load. Other implementations are within the scope of the following claims.